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Guidelines for Line Transect Sampling of Biological Populations

Prepared for: U S Fish & Wildlife Service
Office of Biological Services

by: Utah Cooperative Wildlife Research Unit
Utah State University
Logan, Utah 84322

1976

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Guidelines for Line Transect Sampling of Biological Populations

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1976

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June 14, 1977

Information Memo No. DSC-77-93
Expires 12/31/77

To: All Field Officials

From: Director, DSC

Subject: Transect Inventories: Guidelines for Line Transect Sampling of Biological Populations

A copy of the subject publication is attached. It is important to note that the purpose of the publication as stated on page 2 is to "provide guidelines for design and conduct of field surveys to estimate size or density of biological populations via a line transect sampling frame."

Our present proposed minimum inventory requirements for animal occurrence or occupancy by habitat site do not and should not include population density or estimates (except for traditional big game methods).

Further the subject publication anticipates inventorying or sampling population size or density by species. Although this information may be of use to you for special studies or analysis it should not be used in a basic habitat inventory.

Richard L. Thomas

1 Enclosure
Encl. 1 - Guidelines for Line Transect Sampling of Biological Populations

Distribution (w/encl.)
412 - 2
360 - 2
D 300 - 2
D 531 - 1

Chapter 1. INTRODUCTION

Chapter 2. DEFINITIONS AND ASSUMPTIONS

Chapter 3. SOME IMPORTANT CONCEPTS

Chapter 4. APPLICATIONS
- 4.1 Immotile Populations
- 4.2 Motile Populations
- 4.3 Clustered Populations

Chapter 5. SUGGESTED FIELD PROCEDURES
- 5.1 Measurements and Methods of Searching
- 5.2 Survey Design

SUMMARY

ACKNOWLEDGMENTS

BIBLIOGRAPHY

Chapter 1. INTRODUCTION

The need to accurately and precisely estimate the size or density of biological populations has increased dramatically in recent years. This has been due largely to ecological problems created by the effects of man's rapidly increasing population. Within the past decade, we have witnessed numerous data gathering activities related to the Environmental Impact Statement (NEPA) process or Biological Monitoring programs. Environmental programs related to phosphate, uranium and coal mining and the extraction of shale oil typically require estimates of the size or density of biological populations. The Endangered Species Act has focused attention on the lack of techniques to estimate population size. It now appears that hundreds of species of plants may be protected under this Act, and, therefore, we will need information on the size of some plant populations. Estimation of the size of biological populations was a major objective of the International Biological Program (IBP) (Smith et al. 1975). Finally, we mention that the ability to estimate population size or density is fundamental to efficient wildlife and habitat management and many important studies in basic ecological research.

The estimation of population size is notoriously difficult (Robinette et al. 1974, Gates 1969). Seber (1973) provides a recent review of the general subject. Density estimation through line transect sampling schemes represents a potentially useful, and relatively unexplored methodology. Published attempts to estimate population size from line transect studies date back at least to the work by R. T. King (Leopold 1933). Since that time, there are less than a dozen serious papers on the subject. By comparison, population estimation methods for capture-recapture studies are contained in a scientific literature that is at least an order of magnitude larger.

Density estimation from the use of line transects is typically practical, efficient and inexpensive for many populations. However, Robinette et al. (1974) and others document that most estimators suggested in the literature are less than satisfactory. Many methods are quite biased, sensitive to certain crucial assumptions, or lack estimates of precision (sampling variance).

We believe that two problems are significant and must be addressed before the full advantages of line transect sampling frames can be fully exploited:

1) the basic data are usually not gathered properly, and
2) well-founded analysis and inference procedures have not been developed.

This publication is directed toward the first point. We are convinced that few investigators understand the many important, and sometimes subtle, factors in conducting a survey based on line transects. This is not surprising as the literature on practical field procedures is essentially lacking. *Hence, our objective in this publication is to provide guidelines for the design and conduct of field surveys to estimate size or density of biological populations via a line transect sampling frame.* To the extent possible, the material will be nontechnical and directed to field biologists and biological technicians. Concomitant problems of how many miles of transect (L) to conduct, (i.e., how many observations (n) are needed) are considerations whose proper sphere is mathematical statistics. These determinations (and some others) should be made, in the final analysis, by a trained and competent statistician or quantitative scientist.

We hope to illustrate the practical advantages of line transect studies in estimating a wide variety of animal populations. Immotile populations (e.g., nests, dead deer, yucca and saguaro plants), "flushing" populations (e.g., pheasants and sage grouse) and slow moving populations (e.g., gila monster and desert tortoise) seem particularly suited to line transect sampling methods (Figure 1). Bobwhite quail (flush in coveys) and rabbits may also represent populations whose size can be likewise estimated. At the other extreme are populations such as whales and moles (probability of being seen on the centerline of the transect is less than one) and chukars (assemble in loose groups and run, rather than flush) where line transects are simply not appropriate, at least without additional information (such as the probability of being on the surface at the time of survey!).

This work is part of an on-going project (USFWS contract No. 14-18-0008-1223) to develop the theory and practice of line transect sampling schemes (e.g., assumptions, models, proper data analysis methods, field procedures, etc.). While this publication is directed toward proper field procedures, we are also trying to develop several nonparametric estimators (*a la* Burnham and Anderson 1976) that will be useful as analysis and inference procedures for line transect data. The thrust of this work is to make no parametric assumptions and develop estimation methods that are robust. Work in this general spirit has already been shown to be relatively successful (see Robinette et al. [1974] and Burnham and Anderson [1976] with respect to the Anderson and Pospahala [1970] method). We will publish the results of these efforts along with a comprehensive, easy-to-use computer algorithm at a later date (probably in 1978).

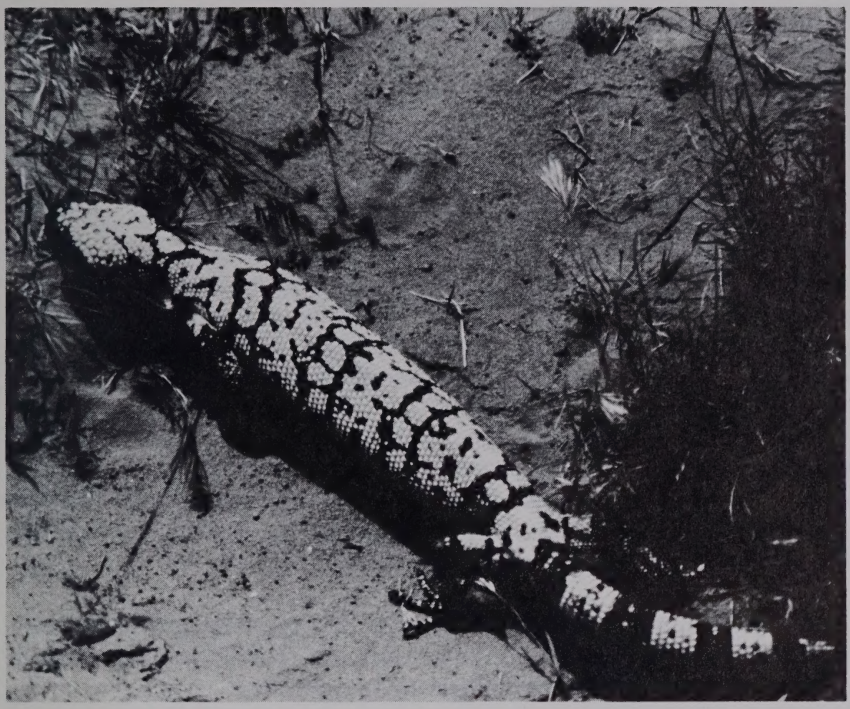

Figure 1. Line transect sampling schemes can be useful in estimating population density of slow-moving reptiles like the Gila Monster. (Photo by Ralph Foote)

Chapter 2. DEFINITIONS AND ASSUMPTIONS

This chapter will contain a geometric and intuitive picture of the line transect sampling method. Consider a two-dimensional plane containing random "points" scattered throughout. These "points" represent the population of interest, which could be mammals, birds, reptiles, amphibians, plants, nests, or whatever the current objects of study might be. Superimposed over this plane is a transect strip or strips which have been located by some scheme determined in advance (we call this scheme the survey design, to be discussed later). A diagramatic transect and the various measurements are shown in Figure 2.

Figure 2 illustrates the various kinds of measurements that can be made once an object is seen. The index i ranges from 1 to n, where n is the number of objects found within the boundaries of the transect strip. If W is finite the transect has area 2LW. We also note that W can be left without a specified finite boundary. In this case only density can be meaningfully estimated.

Since statistical analyses will eventually be made using the data collected, it is of interest to formulate the hypotheses and assumptions that are to be made. First, let us formalize the abstract physical situation:

1) points or objects are distributed independently in the plane according to *some* stochastic process (or random mechanism) with rate parameter D (points per unit area).
2) let a line of known length L be randomly placed in the plane. The line is traversed and a sample of points on both sides is observed along with either or both of the following: 1) right-angle distances, 2) sighting distances and sighting angles. [In practice there are usually several distinct non-overlapping lines (ℓ_i) from which data are pooled. It is not important (but could be of interest) to record which side of the line each object was seen.]

Four assumptions are critical to achieve worthwhile results:

1) points directly on the line are seen with probability one.
2) points are fixed at the initial sighting position (they do not move before being sighted) and *none are counted twice.*
3) there are no measurement errors and no rounding errors (distances are measured exactly).
4) sightings are independent events.

Finally, we present a numerical example taken from Anderson and Pospahala (1970) which dealt with waterfowl nests at the Monte Vista National

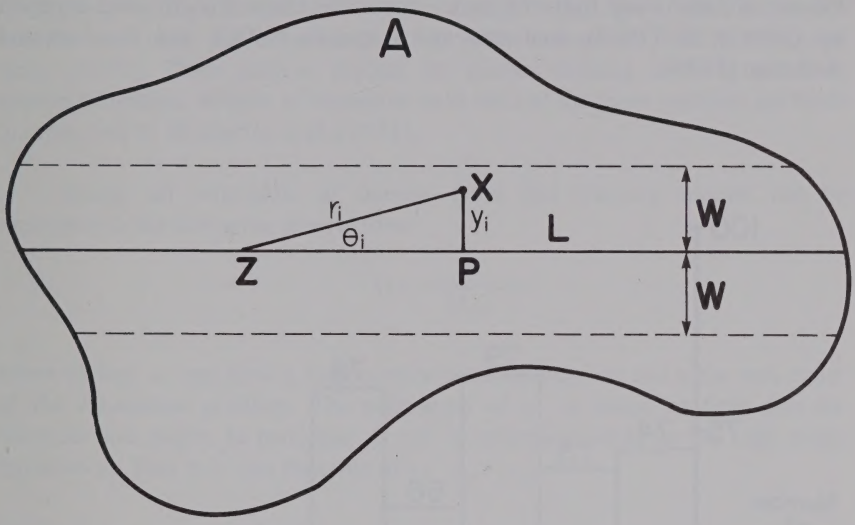

Figure 2. The unit to be censused has area A. The transect length is L and the transect width is 2W. Z is the position of an observer when an animal or object is detected at X. P is the point on the line which is perpendicular to the object. The sighting distance is r_i, the sighting angle is θ_i, and the perpendicular distance from the object to the center line of the transect is y_i. W can be left unspecified or effectively infinite or can be a fixed, finite constant.

Wildlife Refuge, Colorado in 1967-1968. Approximately 10,000 acres of the refuge were systematically sampled by the line transect method. Transect strips 16 feet wide were conducted for a total length of 1600 miles. This gives A = 10,000 acres, L = 1600 miles, W = 8 feet.

Right-angle distance (y_i) was measured for each nest found and the resulting data were accumulated, as shown in Figure 3. Altogether, n = 534 nests were found. This was an extremely large survey, both in terms of L and n. Only right-angle distances were recorded in this survey.

The data in Figure 3 indicate that nests near the centerline of the transect are easier to detect than those farther away. This phenomenon will be common in line transect studies, and reliable statistical analysis of the data must compensate for this kind of a trend. A mathematical way of dealing with this "decay of data" away from the center line of the transect is discussed in papers by Gates et al. (1968), Anderson and Pospahala (1970), and Burnham and Anderson (1976).

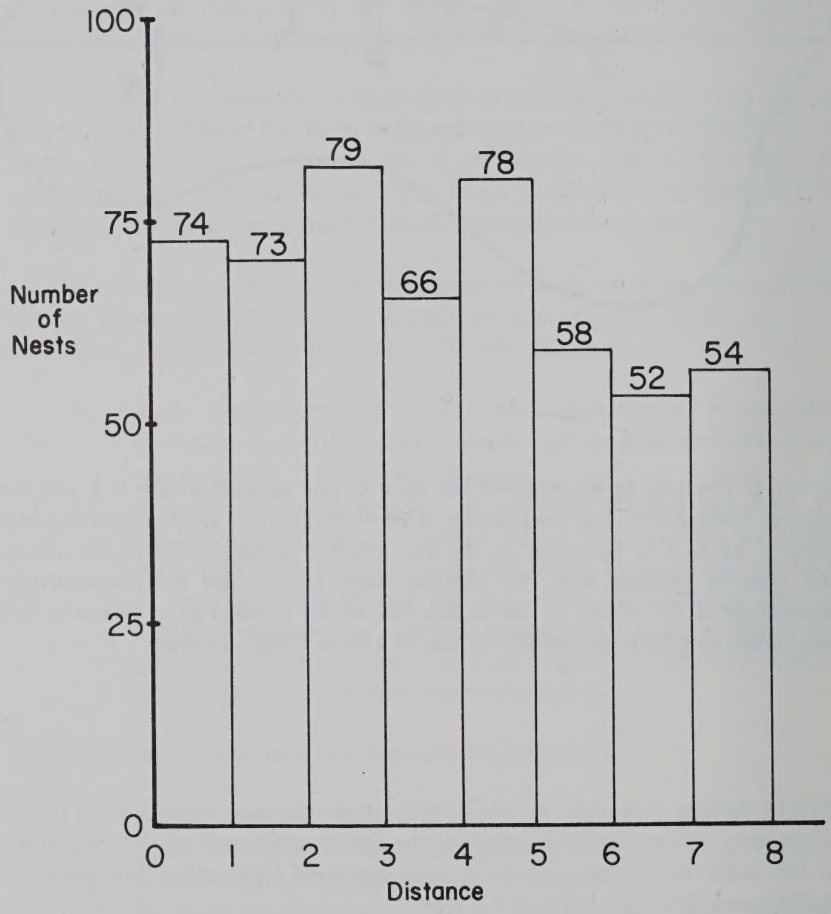

Figure 3. Histogram of waterfowl nest data obtained from line transect samples at the Monte Vista National Wildlife Refuge, Colorado, 1967-1968. Distances are measured in feet from centerline of transect.

Chapter 3. SOME IMPORTANT CONCEPTS

Reviews of published methods for density estimation from line transect studies have been published by Gates (1969), Kovner and Patil (1974), and Seber (1973). These authors explain the various existing methods and their interrelationships. Results of extensive field tests of the more common methods are reported by Robinette et al. (1974).

Nearly all estimators of density from line transect samples can be expressed in the following general form:

$$D = \frac{n}{2L\mu}$$

where in fact μ can have a wide variety of interpretations and is the very heart of the estimation problem. The estimation of μ is based on field data on distances and angles. In particular, it can be estimated solely on the right angle distances y_i. That is $\hat{\mu}$ is a function of $y_1, \ldots, y_n$.

Our purpose in this section is to point out that until recently, the general estimation problem has not received rigorous attention and treatment. Early methods of analysis are based largely on ad hoc procedures and often lacked a firm foundation or theoretical basis. Estimators of sampling variance (a measure of precision) were generally lacking. Since the early 1920s the general statistical subject of "parameter estimation" has advanced to a fairly sophisticated state. Gates et al. (1968) were the first to view properly the estimation of density from line transect data in a standard statistical framework (although the early work of Hayne [1949] should be referenced). Their approach, and that of several others since, was based on a rigorous treatment of the estimation problem, making certain parametric assumptions. The following material will make some important basic concepts of estimation more clear.

First, let us consider an estimator $\hat{\theta}$ of an unknown parameter θ. The estimator $\hat{\theta}$ is a statistic: a random variable whose value can be observed on the basis of a sample. For example,

Sample Data $X_1, X_2, \ldots, X_n$	Estimator $\hat{\theta}$	Parameter θ	Estimate
$9.9, 6.1, \ldots, 7.0$	$\hat{\theta} = \frac{1}{n}\sum_{i=1}^{n} X_i = 7.9$	7.4	7.9

Here, of course, we recognize that $\hat{\theta}$ is merely the mean of the sample. The true value of θ is 7.4 and the estimate of θ, based on the specific sample $X_1, \ldots, X_n$ is 7.9.

Because $\hat{\theta}$ is always a random variable, the particular value it takes on varies from sample to sample. Thus, we would certainly not expect to have the estimate equal the true unknown parameter θ for every sample taken.

Statisticians have defined several properties of estimators; these are useful in deciding the "goodness of an estimator". The most obvious property is the expected value (essentially the mean of a large number of values of $\hat{\theta}$). If the expected value of the estimator $\hat{\theta}$ is θ, then $\hat{\theta}$ is said to be an unbiased estimator.

Generally, we would prefer an estimator to be unbiased but it is not the only criterion to be used in comparing estimators. In a given problem there are generally a large number of unbiased estimators of a parameter, thus we should have at least one additional criterion for judging which estimator is best among all unbiased estimators.

It is obvious that the unbiased estimator with the smallest variance (about the true value of the parameter) would then have the largest probability of being close to the unknown parameter. Generally, in the literature the comparison of variances of estimators is discussed in terms of efficiency (the more efficient estimator has a smaller variance). We see that, if $\hat{\theta}_1$ and $\hat{\theta}_2$ are both unbiased estimators of θ for the same sample, then $\hat{\theta}_1$ is more efficient than $\hat{\theta}_2$ if

$$\text{Var}\,(\hat{\theta}_1) < \text{Var}\,(\hat{\theta}_2) \quad .$$

One classical approach to parameter estimation has been to consider estimators with zero bias, and then within this class to choose the one with smallest variance. Under certain conditions the method of Maximum Likelihood produces estimators with these desirable properties. For example, Gates et al. (1968) employed the Maximum Likelihood method based on the negative exponential distribution.

We might remark at this point, that estimators have other properties such as consistency (bias decreases to zero as the sample size increases) and the sampling distribution of the estimator (e.g., approximately normal). These are often considered in evaluating an estimator.

As we noted above, for line transects the number of points observed decreases as the distance from the center line to the object increases. Good estimators of density mathematically utilize the information expressed by this "drop off" or "decay". Ways to estimate density from such a mathematical relationship fall into two general classes: parametric and nonparametric. These are technical subjects and we will say little about them here because sampling

and data collection do not differ under the two estimation approaches. Basically, a parametric family of statistical distributions may be used to "model" the data as a function of distance from the center line. Examples of parametric families of distributions include the negative exponential, gamma and half-normal. *If* the observed data follow the selected distribution very well, very good estimators (e.g., unbiased, minimum variance, etc.) can be derived. It is also possible to derive estimators without parametric assumptions. This is a more difficult approach but avoids making strong assumptions about the specific mathematical function representing the data. Most importantly, it may avoid the large biases often present when the data do not follow an assumed parametric distribution almost exactly. In this respect, we say the estimator is "robust".

So, we have some criteria and guidelines for choosing an estimator of population density from line transect samples. We want an estimator of density that has minimum variance within the class of unbiased estimators. This procedure seems intuitively appealing and Kovner and Patil (1974) discuss this subject with respect to several published estimators of density. The method of Gates et al. (1968) is shown to be unbiased and minimum variance assuming the parametric negative exponential distribution. These results were expected because Gates et al. (1968) developed their estimator from the Maximum Likelihood method based on the negative exponential distribution. Sen et al. (1974) have attempted to extend the parametric approach based on the more flexible gamma distribution. Unfortunately, a serious error was made in their likelihood function and, therefore, the results are not useful. Pollock (in preparation a) has suggested the use of the exponential power series distribution. This approach may prove interesting but properties of estimators based on this distribution are largely unknown at present. Pollock (in preparation a) notes that the exponential power series distribution includes several of the other parametric distributions as special cases.

Finally, we remark that estimators are dependent, often in a very critical way, upon certain assumptions (Figure 4). Evidence is accumulating to show that the negative exponential distribution is not generally useful as a model for line transect studies. This is indeed unfortunate as we have an "optimal" estimator for this case *if* these assumptions are met (Gates et al. 1968).

We believe that useful estimators should be developed along nonparametric approaches. This might avoid the severe bias often observed when the data do not follow closely an assumed parametric distribution. This suggests that we might be wise to sacrifice a little of the "minimum variance" or "unbiasedness" properties for an estimator that is "robust" to failure of specific distributional assumptions. In other words, we are looking for tradeoffs between unbiasedness, robustness, and minimum variance. If this can be done successfully, it will represent an important advance over both the ad hoc approaches and the modern parametric estimators.

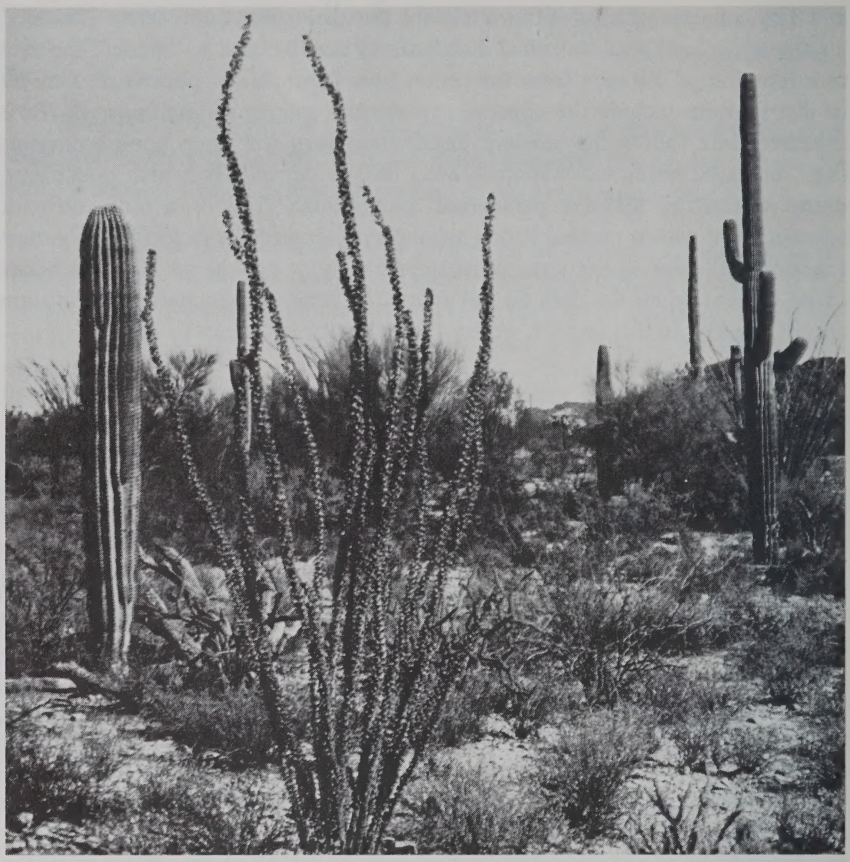

Figure 4. Many plant populations such as the saguaro can be sampled via line transects. Here, the probability of seeing a plant on the center line is most assuredly one. Careful measurements are possible with immotile objects. (Photo by James A. MacMahon)

Chapter 4. APPLICATIONS

4.1 Immotile Populations

Populations whose individuals are fixed and sedentary or move very slowly in relation to the observer are the easiest to survey. The assumptions given in Chapter 2 are most easily met with immotile objects. Obvious examples of immotile populations include surveys of dead deer, land snails, conspicuous plants, and birds nests. Tortoises can probably be considered as immotile for purposes of line transect surveys.

The assumptions given in Chapter 2 are important. The degree to which motile populations can be surveyed depends on the degree to which the basic assumptions can be closely approximated. These subjects are addressed in the following section.

4.2 Motile Populations

Many of the problems associated with line transect sampling are encountered with motile populations. The probability of sighting an animal may be dependent on the response of the animal to the observer. If an animal hides, or runs and then flushes, or if it "drives" in front of the observer, then the assumptions of the model will not be met. Also the accuracy of the measurements is lessened because the determination of the exact position of the animal before flushing is not usually possible.

Consider a study of live deer. Deer in the survey area will simply not stand and be counted. They may often hide motionless in thick cover or perhaps will be evasive and disappear before they can be spotted by the observer. In other words, they may make either a passive or an active effort to go undetected, and this causes difficulties in the proper statistical analyses of the data.

To determine the applicability of the line transect to a certain animal, the behavior and biology of the animal must be examined with respect to the assumptions of the model. Below, four of the assumptions are described in terms of field applications to motile populations and an example, which violates the assumption, is given:

1) *Animals on the line are always seen.* This presents problems in dealing with burrowing animals such as ground squirrels and cottontail rabbits or aquatic animals such as whales or porpoises. An animal could be on the line but hidden by the respective medium.
2) *Animals do not move before being seen or flushed.* The response of an animal may be to shy away from the observer's line of travel without being noticed. If it then proceeds to flush, the observed right angle distance will be exaggerated. Chukars often respond by

running before they flush, making a good survey of their population size quite difficult. [Movement is not critical *if* it is independent of the observer and "slow" relative to the observer's speed along the line].

3) *Animals are not counted more than once.* In response to the observer, some animals will move ahead of the observer near the line of travel. Unless this can be observed and negated, then the animal will subsequently be recounted. Many songbirds are notorious for this type of behavior.

4) *The sighting of animals is independent.* The flushing of one animal does not cause another to flush. Animals which gather in loose flocks such as pinon jays will not be applicable.

Line transect sampling has been used to survey various species of animals including ruffed grouse, snowshoe hare, white-tailed deer, willow ptarmigan, jackrabbits, and elephants. Line transect sampling has capabilities to be extended to many other motile populations if the basic assumptions of Chapter 2 are approximately met.

4.3 Clustered Populations

Animals that aggregate into coveys, schools, and other tight groups are referred to here as clustered populations. Clustered populations can be either motile or immotile (Figure 5). In terms of line transect sampling, each cluster (e.g., covey) is treated as a point and the clusters are assumed to be independent. Distance and angle measurements relate to the geometric center of the cluster as the point of observation. This enables the estimation of the density of clusters. Cluster size must also be determined for each cluster in order to estimate population density of the individual objects. It is essential that the size of each cluster be accurately determined in addition to the measurements of r_i, y_i, and θ_i.

Hayne (1949) considered estimation of the size of populations that were clustered. More recently, Pollock (in preparation b) has attempted to examine the estimation theory of clustered populations. No one has published field methods for such populations. We feel that the line transect sampling scheme can be applied only if the geometric center of the cluster can be adequately determined. Furthermore, the size of each cluster must be determined. Quail and gray partridge often form tight coveys and thus would be applicable. Animals in loose groups can not be appropriately analyzed as a clustered population. They usually do not flush simultaneously and the geometric center becomes nearly impossible to accurately establish. Chukars, pinon jays, and some songbirds fall into this category. Examples of immotile objects occurring in clusters would include plants with poor dispersal mechanisms.

Figure 5. Pheasants, bobwhite quail, porpoise and many plant populations aggregate into coveys, schools, clumps, etc. and are examples of clustered populations. In line transect surveys of such populations each cluster is treated as a point and the size of each cluster must also be recorded in the field.

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Chapter 5. SUGGESTED FIELD PROCEDURES

5.1 Measurements and Methods of Searching

The major advantage of the line transect sampling scheme is the relative ease of its implementation in the field once a proper frame has been chosen. The problems encountered in the field are twofold:

1) defining the straight line of travel,
2) obtaining accurate measurements of distances and angles.

The field procedures to be described are simple; however, understanding them is essential to obtaining good estimates of density.

The entire procedure of line transect sampling is based on being able to follow a *straight* transect line or series of *straight* line segments. This is almost always compromised to some degree in the field because of physical obstacles and the near impossibility of traveling a straight line and searching for objects simultaneously. However, if the line of travel is not defined in some manner, then accurate measurements of right-angle distance and sighting angle cannot be obtained. If the observer tends to walk towards the object once it is sighted, then the right-angle distance and sighting angle are negatively biased and the density estimate is positively biased.

A simple approach to defining the line is to follow a compass line by sighting on landmarks on the line of travel to a point on the horizon. This approach does not necessitate a fixed line but is to be discouraged as precise line placement is essential. Precision can be increased with a more permanent line, by marking the line with flagged or painted stakes at convenient intervals. The interval between markers will depend on their visibility but it can be as large as one half of a mile and provide for accurate measurements. A more elaborate and sophisticated technique involves the use of a transit and walkie-talkies to keep the observer on the line (Figure 6). This technique allows the observer to spend more time in searching for objects instead of concentrating on following the line. It is an ideal method but is limited to open flat areas and requires two people. The use of any one of these methods will be determined by the situation, manpower and the precision required.

In searching for objects the observer scans a semicircle of reasonable radius within which most objects will be sighted while being especially careful not to miss any objects on the centerline. Once an object is sighted, the sighting distance, sighting angle and right-angle distance are measured.

As a *minimum,* the observer can measure either:

1) right-angle distances, y_i,

or

2) sighting distances r_i *and* sighting angles θ_i.

Figure 6. Here walkie-talkies and a transit are employed to assure the observer (background in photo) follows a straight transect line. As objects are found, measurements are radioed back to the base station (foreground).

Until analysis and inference procedures are rigorously developed to indicate a preference for one of the above, we are strongly recommending that all three measurements be taken as each object is found (y_i, r_i and θ_i). This procedure allows the measurements to be checked for gross errors because each measurement can be computed from the other two.

We do not believe that reliable analysis methods can be developed to utilize only information on sighting distances. Very strong and unreasonable assumptions must be made for analysis procedures based on only sighting distances. This makes it essential that straight transect lines must be employed and the observer must

a) conduct the survey in such a way as to maximize the probability that all objects on the center line are found, and
b) be able to accurately determine the center line of the transect once an object is found.

The distance measurements are preferably measured with a steel tape. In many instances long distances and hilly terrain require pacing or using a range finder (Figure 7). We discourage the use of both of these methods and support their occasional use only when it is not practical to measure the distances accurately with a steel tape. Many observers use a stick as a "beater" to aid in locating objects, probing into dense cover, etc. If in these cases, most objects are found fairly close to the center line, a heavy yardstick (or meter stick) may be used to serve the dual purpose as a beater and measuring device. We found that a liquid-filled lensatic compass gave quick and accurate readings of θ_i because of its simple sighting mechanism.

In some situations it may be possible only to assign objects seen to one of several *distance classes* (e.g., 0-15 feet, 15-30 feet, 30-60 feet, etc.). We discourage this practice although we realize it may be necessary in some field situations. We prefer that accurate measurements of the right angle distances be recorded. Then, if grouping is to be done before analysis and estimation, one is free to select the number of intervals and their widths.

We have developed a fairly adequate approach to obtain all three measurements in the field. For immotile objects, with reference to Figure 2, the procedure is as follows:

1) measure sighting angle and place a marker at point Z
2) find point P with a compass reading in the direction of point X, at a right-angle to the line of travel
3) measure right-angle distance from point P to X
4) measure sighting distance from point X to Z.

For motile objects the procedure changes because it is not usually possible to determine the exact position of the animal before it moved. In this case a marker is placed at Z and sighting distance is measured first and a marker is placed at X. Then the sighting angle is measured and finally the right angle distance, as described before. The transit procedure, described previously, simplifies the matter considerably: the observer measures sighting angle, sighting distance to point X and then using a compass walks at a right angle back to the line of travel. The person operating the transit can then tell the observer when he has reached the line. All the measurements can be recorded by the person at the transit, thus the observer need not carry a clipboard, field forms, etc.

The general nature of line transect sampling permits many methods of searching other than on foot. Travel on horseback can be advantageous in many upland situations. Use of a horse can improve visibility and reduce observer fatigue but may cause problems because the horse needs to be secured while the observer takes the measurements once an object is found. Well-trained dogs can be used to flush game birds and help detect other animals. The dogs should work

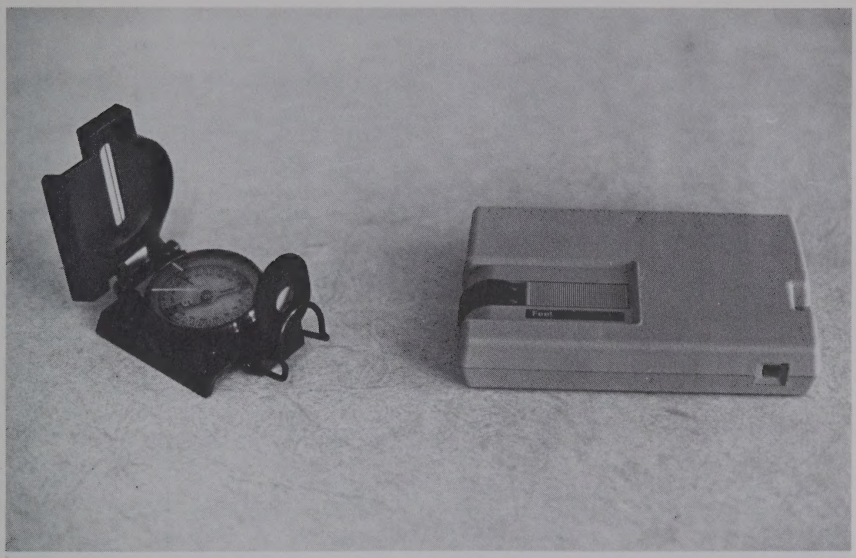

Figure 7. Liquid-filled lensatic compass (left) is adequate for measuring sighting angles in the field. It is important that these angles are measured accurately. A range finder (right) can be used to estimate distances (y_i and r_i) if the terrain is extremely rough (e.g., surveys of Nene geese on lava flows in the Hawaiian Islands). Where possible, use of *a steel tape is recommended for accurate measurements.*

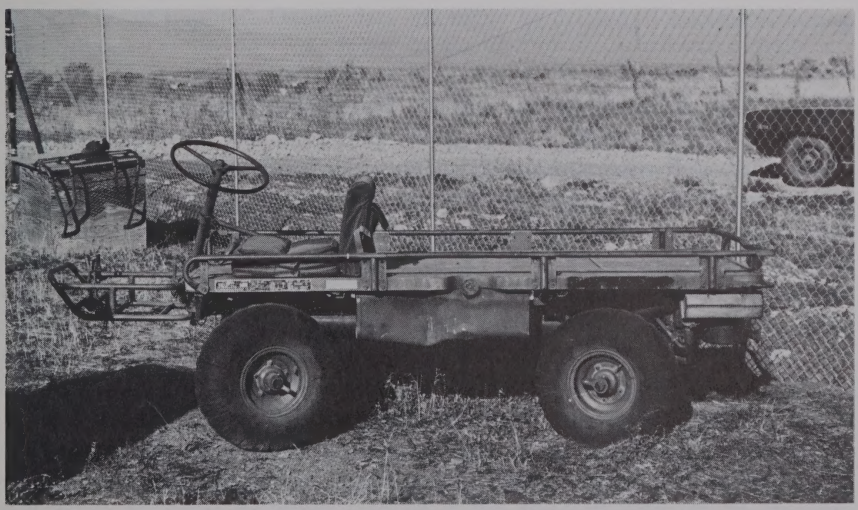

Figure 8. Offroad vehicles can sometimes be used in line transect surveys. Here, an Army Mule is shown: visibility, maneuverability and portability are good.

Figure 9. Accurate measurements are best made using a steel tape. Notice the metal stake used at the center line to facilitate careful measurement.

a fairly tight pattern around the line of travel so that all birds near the line are seen. Offroad vehicles (ORV's) can be used effectively in some situations (Figure 8). Often, this will reduce observer fatigue and increase the coverage (L) per day. If the use of an ORV tends to lessen the chance that objects on the line will be observed, it should not be used.

Applications of line transect sampling for whales or porpoises require the use of a boat or airplane for searching. Basically, any convenient method which does not violate the fundamental assumptions can be used. It is important that the various measurements are not unintentionally (or intentionally) "rounded" to convenient values (e.g., rounded to 5, 10, 15, . . .) (Figure 9).

Lastly, it is crucial that only competent, interested and trained personnel be employed to conduct line transect surveys. This point cannot be over emphasized.

5.2 Survey Design

The method by which the transect strips are to be located or determined is known as survey design. As a general rule, the transect strips should not be laid out too close together, nor should the strips be overlapping. Other considerations are discussed below.

In general some advance information is needed on 1) the biological aspects of the population being studied, and 2) a delineation of the area being surveyed by shape, size and type of habitat. This type of information will enable the survey to be designed so that maximum benefit may be derived from the data in terms of smaller variances, smaller biases, shorter confidence intervals and greater reliability and efficiency overall.

Another aspect of survey design is the problem of how much data to collect. Certain minimal amounts of data need to be obtained to enable the various statistical analyses to be run and valid inferences to be drawn. The other side of the coin is that too much data can also be a problem, in that cost is often nearly proportional to sampling effort (primarily to line length, L). Certainly these two considerations need to be balanced as an integral part of the survey design. As a practical minimum, studies should be designed to assure that at least 40 objects ($n > 40$) are seen and it might be preferable if the length (L) of the survey were sufficient to allow the location of at least 60-80 objects ($n > 60\text{-}80$). Furthermore, we recommend that the width (W) of the transect be taken as large (with respect to the average right angle distance expected), or effectively unbounded. Mathematically $W = \infty$ is theoretically advantageous; finite W is not required. Outlier data can easily be deleted, if necessary, during the analysis.

Biological considerations will usually be important in line transect sampling work. For example, if we are sampling a type of plant, then counts along one transect line should not appreciably affect counts along neighboring transect lines, since plants are stationary and nonevasive. On the other hand, if we are sampling deer, then it would be important to place different transect lines some distance apart, because the execution of one transect line could conceivably influence counts along nearby transects. Statistically speaking, one would like counts along different transect lines to be "independent" random variables.

The placement of transect lines could be on either a temporary or permanent basis. If the survey is a one time occurrence then temporary lines would be appropriate. One could also consider permanent transect lines delineated by poles or other markers if the transects were to be repeated periodically, such as might be the case in a long range study (Figure 10). Use of permanent transects would allow "pairing" of the data for analyzing differences in density over time and thereby increase the power of such an analysis.

Figure 10. Permanent transect markers such as the one pictured here are ideal if the survey is to be replicated. 12 x 15 inch plywood is used and attached to an eight foot pole or pipe.

A delineation of the entire survey area by shape, size, boundaries, and type of habitat would be a necessity in many studies. For example, consider a hypothetical waterfowl nest survey in a hypothetical valley floor depicted in Figure 11. Suppose we are interested in estimating the number of waterfowl nests in this valley, using the line transect survey method. Once the potential nesting area is determined (marshland), we would randomly sample the marshland and obtain our data. This could be done by 1) dividing the marsh into disjoint portions, and randomly selecting those portions to be sampled. Then, 2) randomly chosen transect lines are placed within the randomly selected portions of the marsh.

In contrast, suppose we wish to sample a relatively homogeneous sagebrush covered region for jackrabbits. Then we would need a design for the transect lines but delineation of the region by habitat would be essentially meaningless, since it is the same throughout the region.

Other types of variables could be used to delineate the survey region by habitat. Some of these are elevation, type and amount of cover, slope of terrain, soil type, temperature and rainfall characteristics, availability of food sources, etc. Selection of important variables will in general depend on both biological and geological (or ecological) considerations.

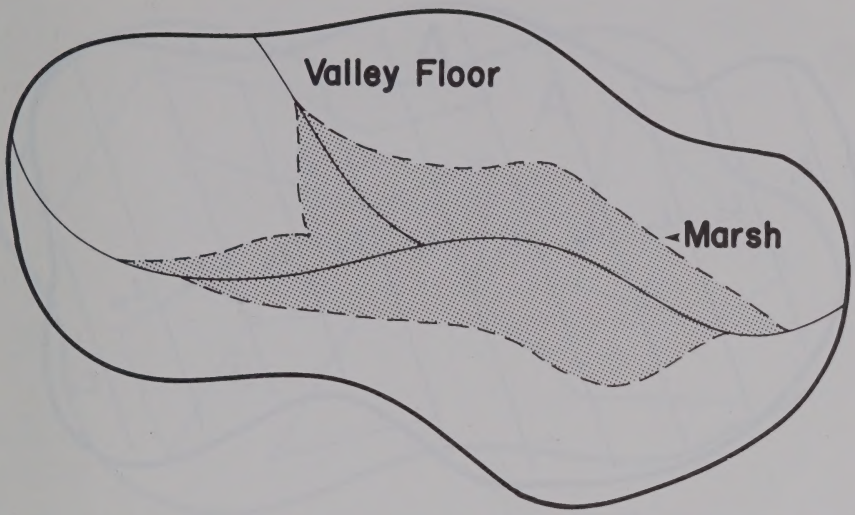

Figure 11. A hypothetical valley with streams indicated as solid lines and marshland indicated by the shaded area.

Once a determination of the regions to be surveyed has been made, the survey design must be chosen. This design will vary according to statistical design requirements, biological and ecological factors, as well as considerations of logistics, supply, and access. Some possible choices of design are given in Figures 12-16. These designs suggest some of the possible arrangements, but are by no means an exhaustive listing. Other sampling designs may occur to the reader.

Designs illustrated in Figures 12-14 are preferred, although the design in Figure 14 is not particularly attractive in the field. Individual line segments (ℓ_j) have been arbitrarily numbered in Figures 12-15. Data (y_i, r_i and θ_i) should be recorded separately for each line segment. An example field form is shown in Appendix A as we recommend the use of a form to aid in keeping carefully recorded data.

Selection of a survey design is thus not a simple or automatic process. By a careful consideration of the relevant factors involved, one can usually adopt an efficient and practical design that will yield informative and meaningful data. Two important principles that apply are 1) to obtain enough valid data to conduct the proper statistical analyses, and 2) to avoid systematic errors or biases in the data, such as highly correlated or statistically dependent transect lines.

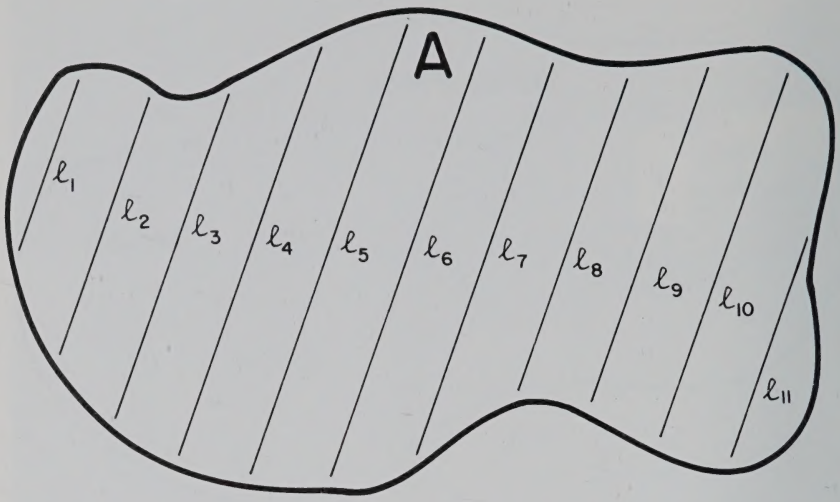

Figure 12. Transect lines chosen in a systematic or non-random fashion. The initial transect location is usually selected as a random distance from the boundary of the area to be surveyed.

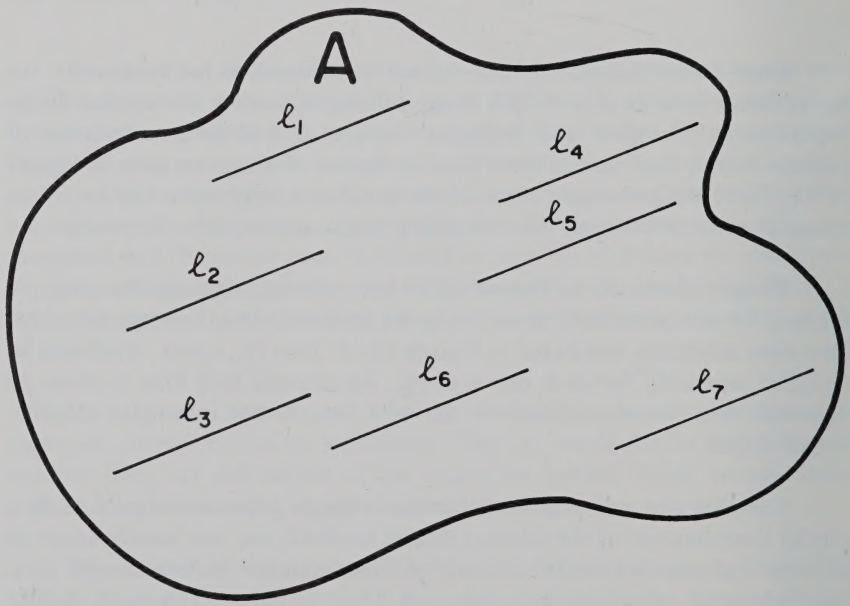

Figure 13. Transect lines selected with random starting points and common (but random) direction. Lines may be of equal or unequal length. Note, $L = \Sigma \ell_i$.

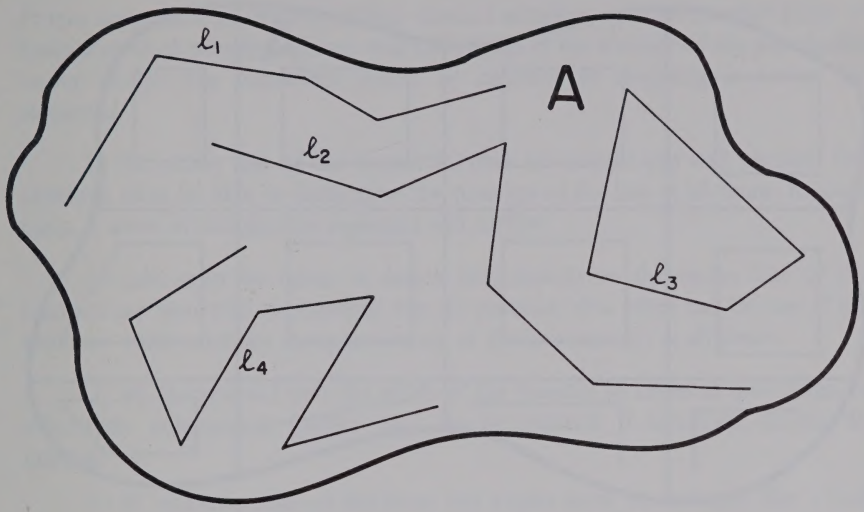

Figure 14. Piece-wise linear transects. This design might be necessary in rugged or nonhomogeneous terrain.

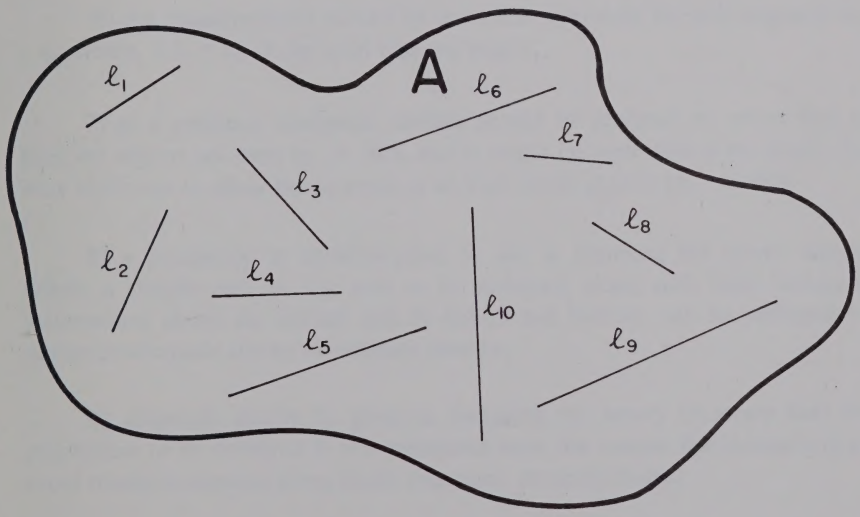

Figure 15. Transect lines selected with random starting points, lengths, and directions. The lines should not intersect or cross.

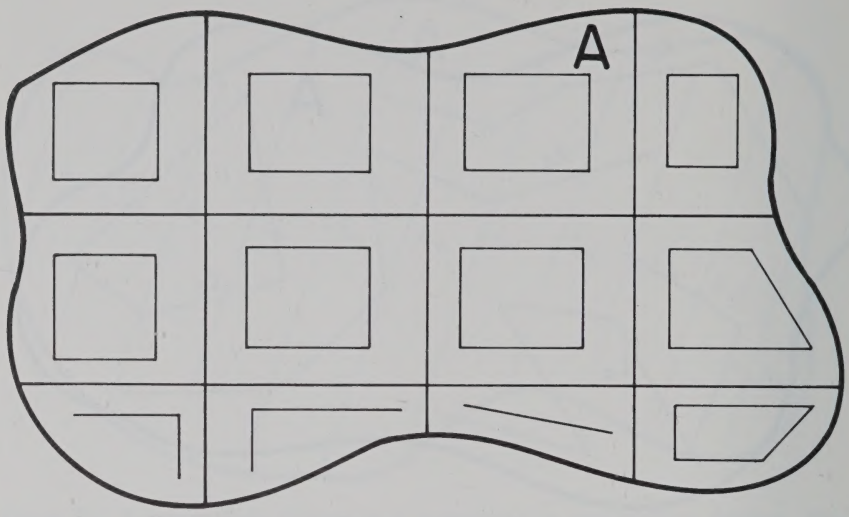

Figure 16. The region A is divided by sections and each section is sampled separately. A variety of designs might be used within each section.

SUMMARY

Proper estimation of density via line transect sampling schemes involves a mix of basic statistical sampling theory and knowledge of the biology of the population under study. *Ten important points to consider in designing a survey are suggested:*

1) the center line of the transect(s) must be straight and well marked. The observer must be able to determine the position of the line at all times. In some cases, a series of straight line segments will suffice.

2) care must be taken to assure that objects on the center line of the transect are seen with probability one. In practice, this often can be met if the observer walks carefully along the center of the line transect at all times.

3) we recommend that the width of the transect be taken as quite large, or effectively unbounded. Outlier data can be deleted, if necessary, during the analysis.

4) all measurements of distances and angles must be accurate. Use a steel tape or other appropriate device to assure a high degree of accuracy. Careless measurements and rounding errors lead to poor estimates of density and sampling variances.

5) at this time, we are recommending that all three basic measurements be taken: right-angle distance, sighting (flushing) distance, and sighting (flushing) angle.

6) the measurements should be recorded separately for each segment (say ℓ_i, where $\Sigma \ell_i = L$) of the total transect length.

7) as a practical minimum, studies should be designed to assure that at least 40 objects are seen ($n > 40$), and it might be preferable if the length (L) were sufficient to allow the location of at least 60-80 objects ($n > 60$-80).

8) a pre-survey is recommended to aid in planning the survey design. Often, a simple visit to the area to be surveyed, along with basic biological information about the animal and its habits and habitat, will be sufficient to design an adequate survey to estimate density.

9) attention should be given in designing the survey to assure that the population to be surveyed is not correlated with the sample line transects (e.g., avoid transects running along roads, ridgetops, streambottoms).

10) the survey should be conducted using competent, interested, and trained personnel. This point is particularly important concerning points 1, 2 and 4 (above).

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APPENDIX A

Example Field Form

Name of Area _____ Date _____

Observers _____ Measurement Scale _____
(e.g., feet, meters, etc.)

Object Number i	Transect Number/ Length	Right-Angle Distance y_i	Sighting Distance r_i	Sighting Angle θ_i	Cluster Size	Remarks

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